

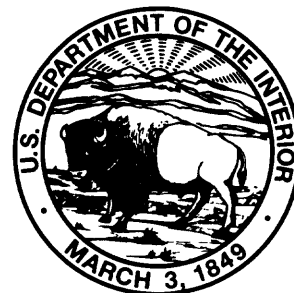
GROUND-WATER QUALITY RECONNAISSANCE, TUTUILA, AMERICAN SAMOA, 1989

By Paul R. Eyre

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Conversion Factors

	Multiply	By	To obtain
	foot (ft)	0.3048	meter
	foot per day (ft/d)	0.3048	meter per day
	million gallons per day (Mgal/d)	0.04381	cubic meter per second
	inch (in.)	25.4	millimeter
	inch per month (in/mo)	2.54	centimeter per month
	inch per year (in/yr)	2.54	centimeter per year
	mile (mi)	1.609	kilometer
	square mile (mi ²)	2.590	square kilometer

Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by using the equation:

$$^{\circ}\text{F} = 1.8 \times ^{\circ}\text{C} + 32$$

Air temperature is given in degrees Fahrenheit (°F), which can be converted to degrees Celsius (°C) by using the equation:

$$^{\circ}\text{C} = (^{\circ}\text{F} - 32)/1.8$$

Abbreviations used in water-quality descriptions

mg/L, milligram per liter

meq/L, milliequivalent per liter

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Abstract

In May and July 1989, 19 ground-water samples were collected from 17 of the 35 water-supply wells on the island of Tutuila, American Samoa. Samples were analyzed for temperature, pH, hardness, specific conductance, turbidity, total and fecal coliform bacteria, major ions, major nutrients, 12 common metals, and 66 organic compounds. Chemical analysis of the water samples shows that, after chlorination, sampled ground water was in compliance with U.S. Environmental Protection Agency primary drinking-water regulations.

Fourteen of the 19 samples were collected before the water was chlorinated in the water distribution system, and five were collected after chlorination. Seven of the 14 unchlorinated samples contained coliform bacteria and five of the seven contained fecal coliform bacteria, indicating potential contamination from disease-causing pathogens. All five of the chlorinated samples contained trace levels of trihalomethanes, but at concentrations below U.S. Environmental Protection Agency maximum contaminant levels. Trihalomethanes were the only organic constituents detected.

Concentrations of total dissolved solids in the 19 samples ranged from about 100 to 2,400 milligrams per liter. Four samples had concentrations of total dissolved solids and chloride that exceeded the U.S. Environmental Protection Agency secondary drinking-water regulations of 500 and 250 milligrams per liter, respectively. For samples with less than 300 milligrams per liter of dissolved solids, sodium, calcium, magnesium, and bicarbonate were the dominant ions, indicating that they were derived from dissolution of minerals and carbon-dioxide enrichment of recharge water. For samples with greater than 300 milligrams per liter of dissolved

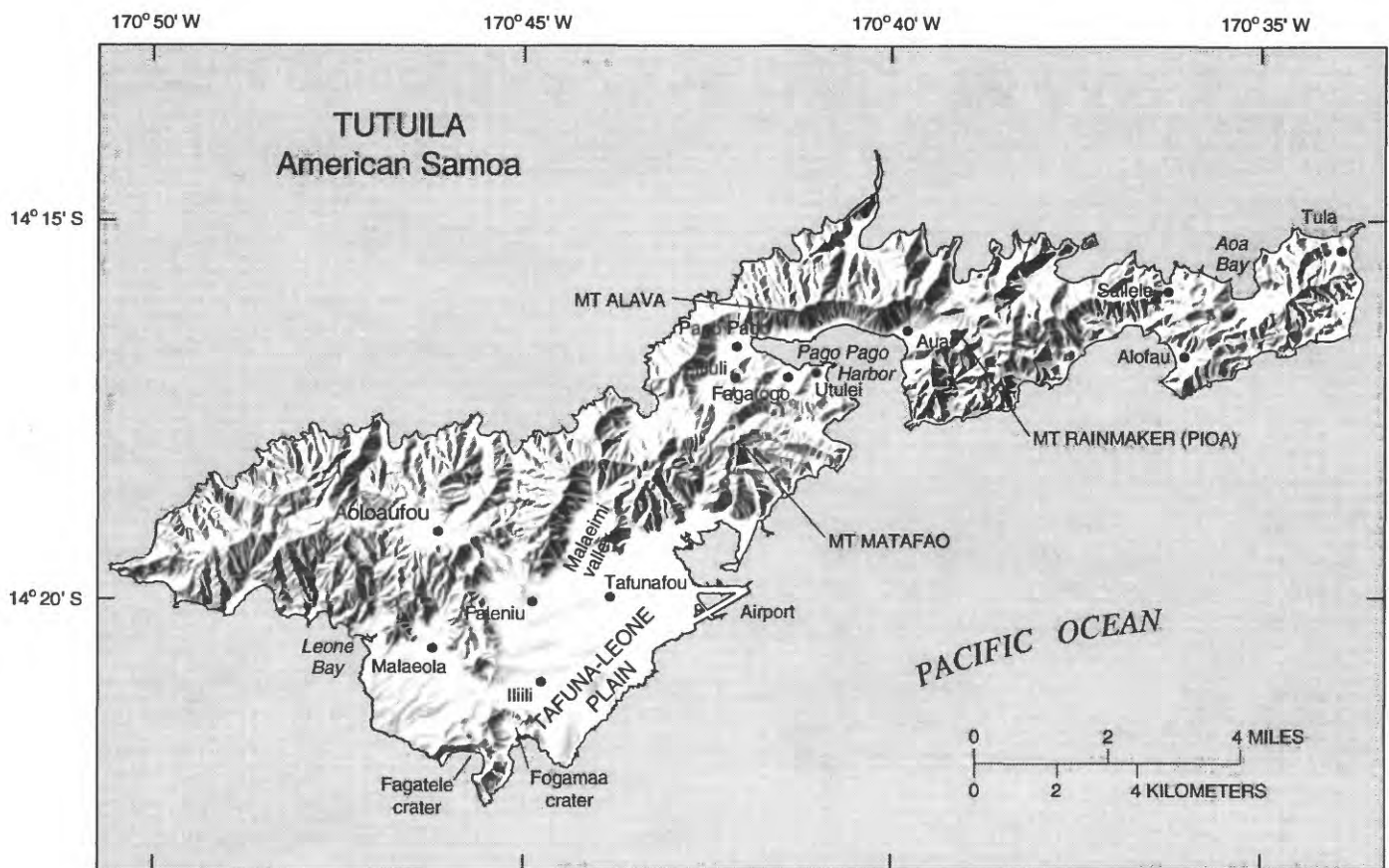
solids, sodium and chloride were the dominant ions, indicating increased mixing of ground water with seawater.

INTRODUCTION

The population of the island of Tutuila increased from 30,000 in 1980 to 45,000 in 1990 (U.S. Department of Commerce, 1981 and 1991) and ground-water pumpage increased from 3 to 6 Mgal/d during the same period. The quality of ground water on the island is affected by differences in hydrogeologic settings, land use, and local well-field operations. Concern for the quality of Tutuila ground water arises from rapid development during in the last decade and the increased dependence on ground water to meet domestic and commercial needs. To address this concern, the U.S. Geological Survey (USGS) undertook this study in cooperation with the American Samoa Environmental Protection Agency (ASEPA) to provide an assessment of ground-water quality at drinking-water wells throughout the island.

PURPOSE AND SCOPE

This report describes the quality of pumped ground water throughout the island of Tutuila at the time of sampling. In May and July 1989, pumped ground-water was sampled at 17 of the 35 pumping wells on the island. Two wells sampled in both May and July brought the total number of samples to 19. Water was sampled from wells in each of the two main geohydrologic units on the island, and in all parts of the island where drinking-water wells were located. Samples were obtained in residential areas, areas of commercial agriculture, and areas relatively undisturbed by human activity. Water quality is described mainly with regard to the primary and secondary drinking-water regulations of the U.S. Environmental Protection Agency (1986, 1989a, 1989b), but is also briefly discussed with regard to hydrogeologic processes, land uses in the vicinity of pumping wells, and local well-field operations.



Base modified from U.S. Geological Survey,
Tutuila Island, 1:24,000, 1963
Shaded relief from Atlas of American Samoa,
University of Hawaii Cartographic Laboratory, 1981

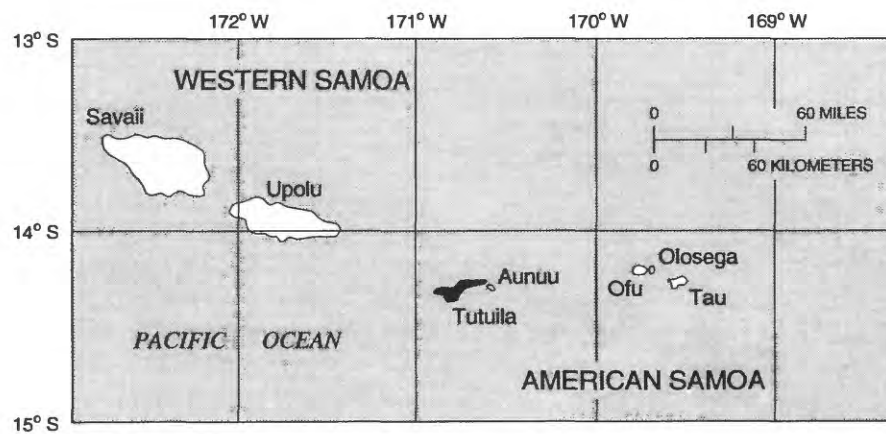
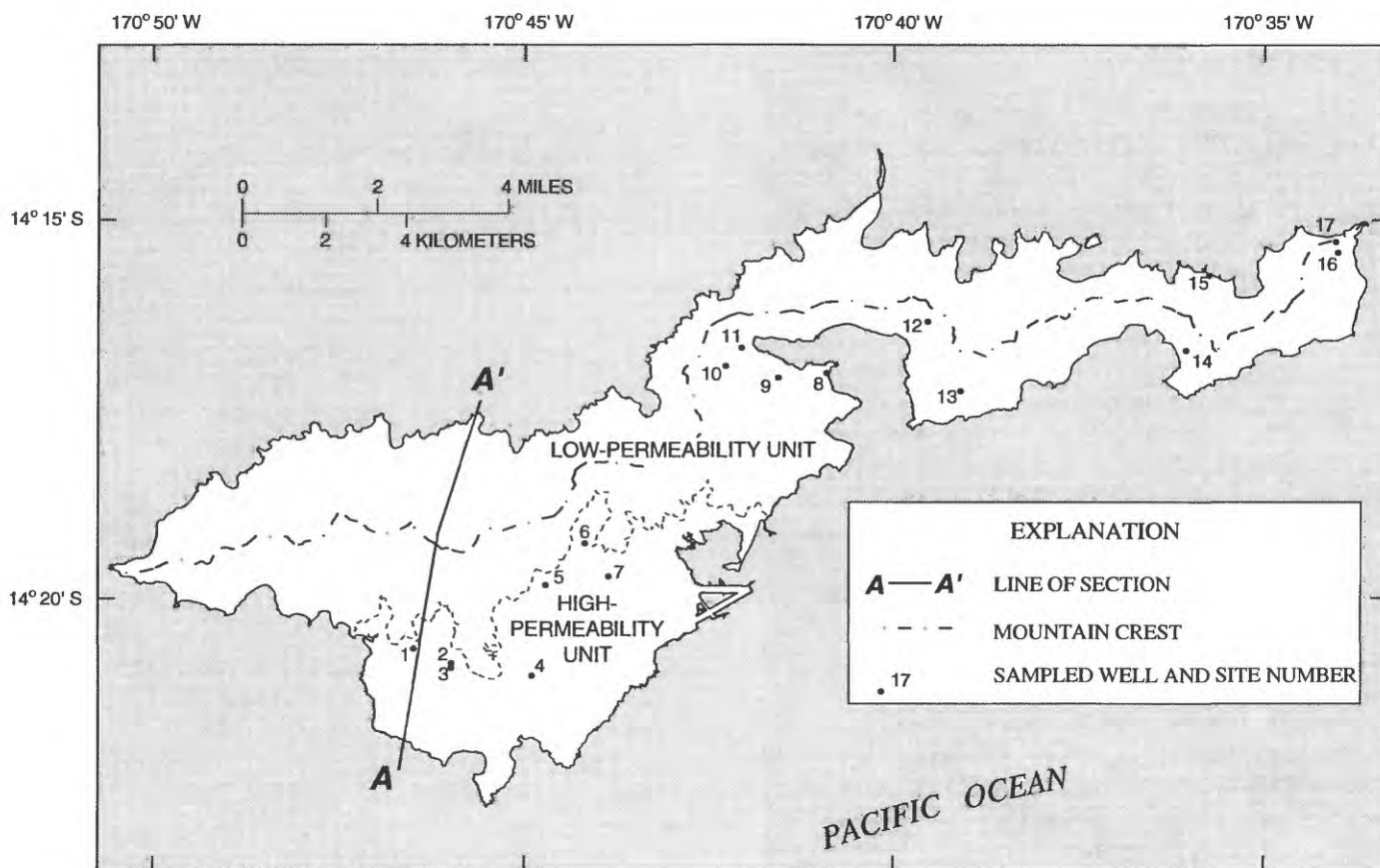


Figure 1. Location of Samoan archipelago and island of Tutuila, American Samoa.



Base modified from U.S. Geological Survey
Tutuila Island, 1:24,000, 1963

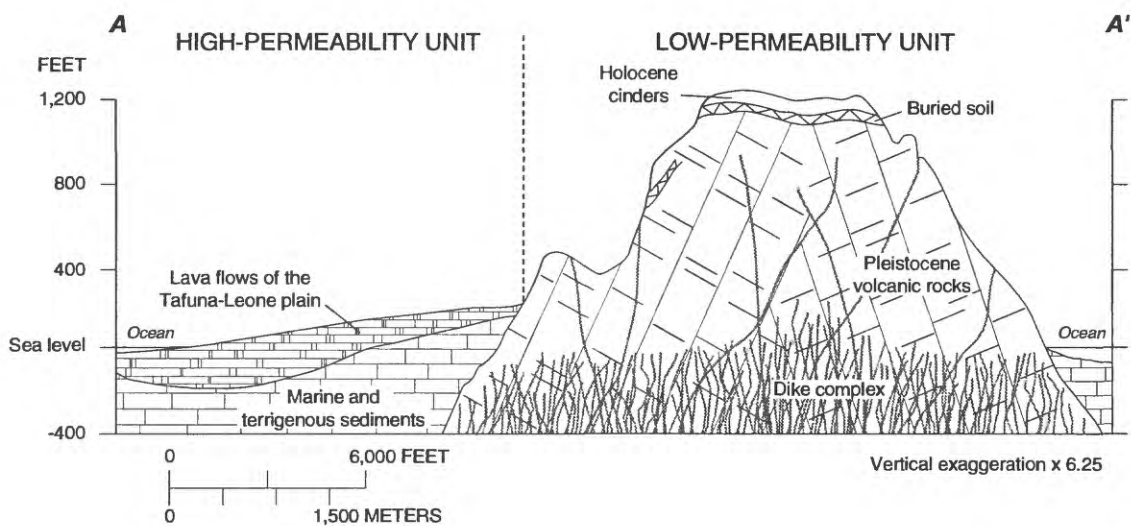


Figure 2. Locations of wells sampled in 1989 and generalized geohydrologic units, Tutuila, American Samoa.

GEOGRAPHIC SETTING

Tutuila is a 53 mi² island at latitude 14°S and longitude 170°W and is the largest and most populated of the islands of American Samoa, which together with the islands of Western Samoa form the Samoan archipelago (fig. 1). The climate is tropical and has an average temperature of about 80°F. The climate from April through October is characterized by southeasterly tradewinds and moderate rainfall, which averages 10 in./mo. Average annual rainfall on the island is 150 in., ranging from 94 in./yr near sea level at the east and west ends of the island to 250 in./yr on the central mountain crest above Pago Pago Harbor at an altitude of 1,610 ft above mean sea level. December through February is the rainy season with occasional typhoons. In December, the wettest month of the year, the airport weather station, at an altitude of 20 ft, receives an average of 14 in. of rain. The peak at Aoloaoufou, at an altitude of 1,340 ft, receives an average of 23 in. of rain in December.

The island comprises two physiographic areas, the main volcanic edifice of steep and rugged topography where the tallest peak (Mt. Matafao) rises to an altitude of 2,142 ft about 1 mi from shore, and the flat 11 mi² Tafuna-Leone plain formed by a lava flow that flooded the fringing reef off the south side of the island during Holocene time. The island is 20 mi long and 2.5 mi wide and is nearly bisected by Pago Pago Harbor. The north and south sides of the island are sharply separated by an east-west central mountain crest flanked by narrow valleys and sharp ridges in most places. Flatlands on the island are limited to the Tafuna-Leone plain, the narrow coastal bench, the floors of larger valleys, and the summit area of Aoloaoufou in western Tutuila.

GEOHYDROLOGY

Tutuila is made up of two main geohydrologic units that correspond to the two physiographic areas. About 75 percent of the area of the island is composed of volcanic rocks of Pleistocene age of the main volcanic edifice (McDougall, 1985). These rocks and the marine and terrestrial sediments that were deposited on them have low to moderate permeabilities (Davis, 1963) and are collectively called the low-permeability unit in this report (fig. 2). The remaining area of Tutuila is occupied by the Holocene volcanic rocks of the Tafuna-Leone plain (Stearns, 1944). These young lava flows and pyroclastic cones have moderate to high permeabilities (Davis, 1963) and are referred to as the high-permeability unit in this report. The high-permeability unit of the Tafuna-Leone plain overlies the

more voluminous low-permeability unit that constitutes the main bulk of the island.

Basal ground water is the primary source of drinking water on Tutuila. Basal ground water occurs as a lens of freshwater that floats on underlying saltwater in approximate accordance with the Ghyben-Herzberg principle: for every foot of freshwater above sea level, about 40 ft of freshwater extends below sea level (fig. 3). The freshwater lens is thinnest near the shore, where basal water levels are near sea level, and thickens inland as water levels increase. The highest basal water level measured was 67 ft above sea level, at site 10 (fig. 2) in Fitiuli, which is 2,000 ft from the shore in the Pago Pago Harbor area. The general direction of basal ground-water flow is toward the shore from the central mountain crest. Near the shore, ground water discharges to the ocean and into low-lying surface waters. Water levels are 3 to 6 ft above sea level throughout most of the Tafuna-Leone plain. Because saltwater underlies freshwater everywhere, saltwater upconing can occur where wells are deep and pumping rates are high.

High-level aquifers form where materials of low permeability retard the downward percolation of ground water (fig. 3). Small high-level aquifers are the sources of many seeps and springs throughout the island. Discharge from a large high-level aquifer at the summit area at Aoloaoufou provides the base flow of several streams.

Water levels, bacteria concentrations, and turbidity of water abruptly increase and subsequently decrease in the high-permeability unit after rainstorms (Samoa Environmental Quality Commission, written commun., 1984; Kennedy and others, 1987), indicating that ground-water recharge is rapid in the high-permeability unit. Similar responses have not been observed in the low-permeability unit, indicating that ground-water recharge is slower and more steady in the low-permeability unit. Because of its high-permeability, high rates of recharge, and relatively shallow depth to basal ground water, the Tafuna-Leone plain is the most productive and developed aquifer on the island. However, for these same reasons, the Tafuna-Leone plain is also where ground water is most susceptible to contamination by human activities such as waste disposal and agriculture.

GROUND-WATER QUALITY

The concentrations of chemical constituents in the ground water of Tutuila were analyzed in water from 17 drinking-water wells in both the high- and low-permeability rock units of the island (fig. 2). Significant temporal variation in major ion and bacteria

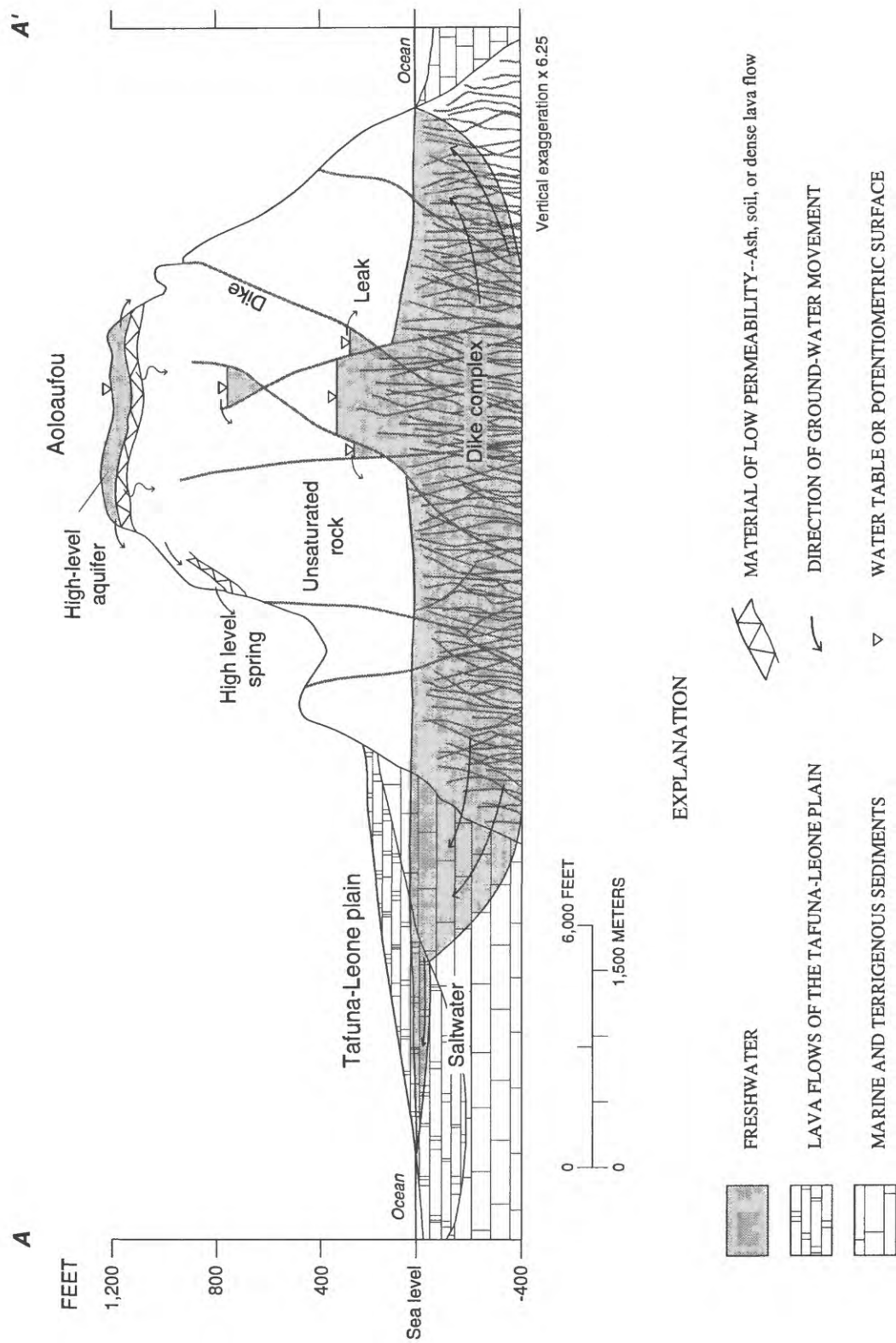


Figure 3. Generalized geohydrologic section of Tutuila, American Samoa (for line of section A-A' see fig. 2).

concentrations has been reported at some wells (Bentley, 1975, Kennedy and others, 1987); however, further investigation of temporal variation in water quality was beyond the scope of this study.

Wells are identified on maps in this report by site numbers (fig. 2); site numbers and corresponding Samoa well numbers are shown in table 1. Sites 1 through 7 are in the high-permeability unit and sites 8 through 17 are in the low-permeability unit (fig. 2). Land use in the vicinity of sites 1 through 7 is agricultural and residential (fig. 4); sites 8, 10, and 11 are in residential areas; and the rest of the sites are on the outskirts of densely to sparsely populated areas. Residential areas were defined by the location of buildings on the 1:24,000-scale USGS topographic map of Tutuila Island (1989). Areas of commercial agriculture, sewerage areas, and the chemicals most commonly used (listed in table 4) were identified by the staff of the Land Grant and Agriculture departments of the government of American Samoa (oral commun., 1989).

SAMPLING AND ANALYTICAL METHODS

Water samples were collected and processed according

to the procedures documented by Brown and others (1970); Wershaw and others (1983); Britton and Greeson (1989); Fishman and Friedman (1989); and M.A. Sylvester, L.R. Kister, and W.B. Garrett (USGS, written commun., 1990). Samples were collected from metal spigots tapping the main distribution line at the wellhead. Water was allowed to flow for ten minutes or more before sampling. When appropriate, sample bottles were pre-rinsed with sample water. Samples to be analyzed for dissolved constituents were filtered through a 0.45-micron Millipore glass filter at the well at the time of sampling. Field analyses of temperature, pH, and specific conductance were made at the well. Samples to be analyzed for metals were preserved with mercuric chloride or nitric acid, as appropriate. Samples to be analyzed for volatile organic compounds were collected in amber-colored glass bottles capped with a plastic septum from which all air was removed before sealing. Samples to be analyzed for constituents sensitive to photochemical reactions were collected in amber-colored bottles. Samples for bacteriological analysis were collected in sterile glass bottles and cultured within 6 hours at the ASEPA environmental laboratory at the Lyndon B. Johnson Hospital.

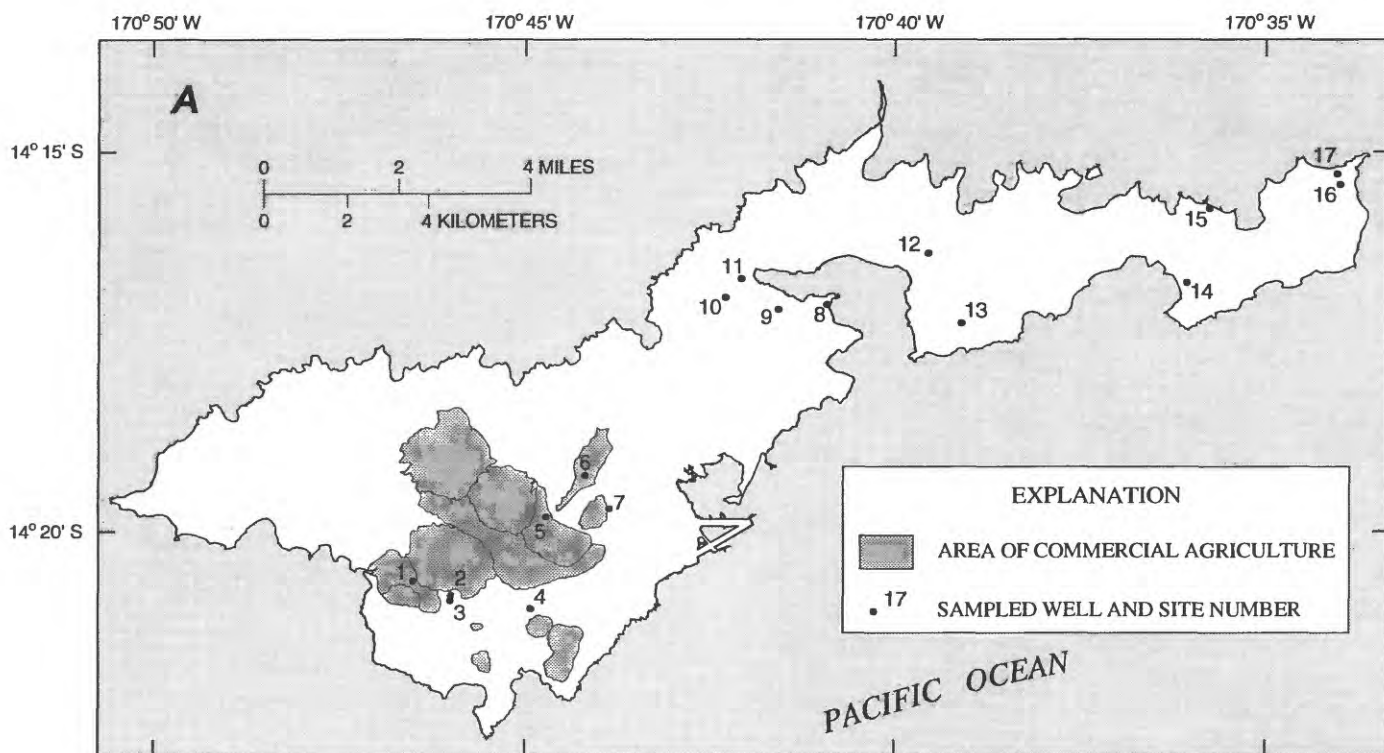
Table 1. Summary of site characteristics and chemical analyses of ground water, Tutuila, American Samoa, May and July 1989

[MCL, maximum contaminant level (U.S. Environmental Protection Agency, 1986, 1989b); --, none or not detected; do., ditto]

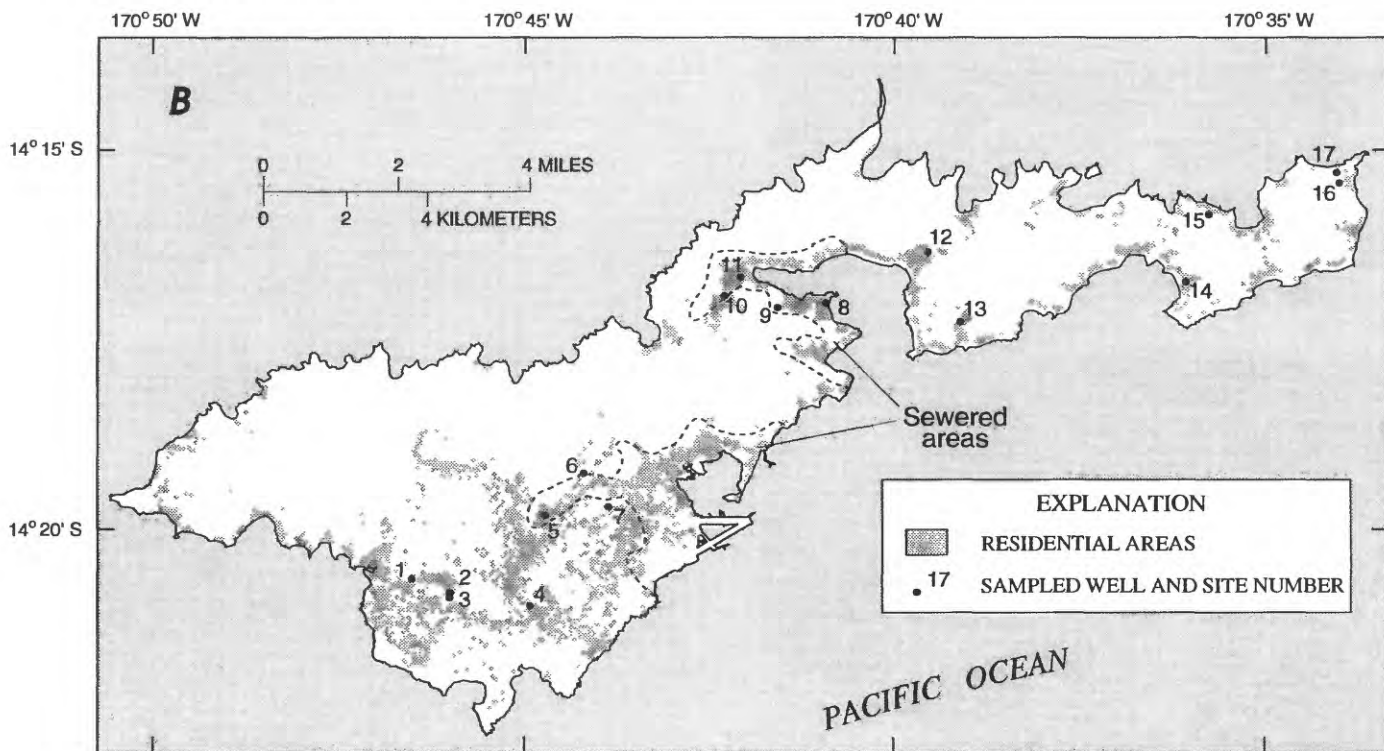
Site no. (fig. 2)	Samoa well no.	Geohydrologic unit	Land use	Sample chlorinated (yes/no)	Coliform bacteria	Trihalome- thanes	Sample exceeding MCL for total dissolved solids and chloride concentration
1	Malaelo 70	high permeability	agricultural/ residential	yes	—	X	—
2	Malaelo 91	do.	do.	no	—	—	—
3	Malaelo 93	do.	do.	yes	—	X	—
4	Ilili 79	do.	do.	no	—	—	—
5	Masepa 85	do.	do.	no	X	—	—
6	Malaeimi 89	do.	do.	no	X	—	—
7	Tafuna 33	do.	do.	no	X	—	X
8	Utulei 3	low permeability	do.	no ¹ /yes ²	X ¹	X ²	—
9	Fagatogo 102	do.	residential	no	—	—	—
10	Fitiuli 107	do.	do.	no	—	—	—
11	Pago Plaza 2	do.	do.	no	X	—	—
12	Aua 99	do.	do.	no	—	—	X
13	Laulii 96	do.	do.	no	X	—	—
14	Alofau 32	do.	do.	no	—	—	X
15	Sailele 130	do.	do.	yes	—	X	X
16	Tula 104	do.	do.	no	—	—	—
17	Tula 108	do.	do.	yes	—	X	—

¹ Unchlorinated sample, July 1989

² Chlorinated sample, May 1989



Base modified from U.S. Geological Survey
Tutuila Island, 1:24,000, 1963



Base modified from U.S. Geological Survey
Tutuila Island, 1:24,000, 1963

Figure 4. Locations of sampled wells and **A**, areas of commercial agriculture and **B**, residential and sewerage areas, Tutuila, American Samoa, 1989.

All samples were immediately placed in ice-filled coolers and shipped, generally within 48 hours, by overnight carrier. Coolers were unloaded in Honolulu 8 hours later, repacked in fresh ice, and shipped to the USGS National Water Quality Laboratory in Denver, Colorado. Field blanks and blind duplicate samples were not collected owing to the high cost of analysis. Blank and spiked reagent water were analyzed with each sample in the laboratory for quality control.

Water samples were collected at pumping wells and therefore were composite samples of water entering the full length of the wellbores. The integrity of the sanitary grout seal around each well probably varied among wells because of their different ages and methods of construction. At some wells, the water quality could have been affected by water that had leaked down the well bore (Kennedy and others, 1987). Fourteen samples were collected before the water was chlorinated, five were collected after chlorination.

Water samples were analyzed for temperature, pH, hardness, specific conductance, turbidity, total and fecal coliform bacteria, major ions, major nutrients, 12 common metals, and 66 organic compounds that included insecticides, herbicides, and volatile organic compounds. Constituents regulated by the U.S. Environmental Protection Agency (USEPA) primary drinking-water regulations were included in these analyses. Reporting limits were well below maximum contaminant levels established by the USEPA (1989a). Results of these analyses are summarized in tables 2 and 3, where constituents regulated by the USEPA are marked with an asterisk. Effects of geochemical processes and seawater mixing are discussed in this report through an evaluation of the major ions; effects of human activities are discussed through an evaluation of coliform bacteria and organic compounds.

Summary of analyses.--All regulated constituents, except fecal coliform bacteria, were below the maximum contaminant levels (MCLs) established in USEPA primary drinking-water regulations (1986, 1989a). Coliform bacteria were found at sites 5, 6, 7, 8, 11, and 13. Fecal coliform bacteria were found in unchlorinated samples that were collected at site 7 in May and in July. Fecal coliform bacteria were found in an unchlorinated sample that was collected at site 8 in July; no fecal coliform bacteria were found in a chlorinated sample collected in May from site 8.

Dissolved solids and chloride concentrations in water from four wells (at sites 7, 12, 14, and 15) exceeded the MCL of 500 mg/L and 250 mg/L, respectively, suggested in USEPA secondary drinking-water regulations (1989b).

Ground-water is mostly of the sodium-magnesium-calcium-bicarbonate type, but sodium and

chloride generally become the dominant ions with increased seawater mixing.

Trace amounts of trihalomethane (THM) were present in chlorinated water at five wells and highest amounts were present when chlorinated disinfectants were injected directly into the well. Water samples were collected after chlorination and THM was detected at sites 1, 3, 8, 15, and 17.

TOTAL AND FECAL COLIFORM BACTERIA

Fecal coliform bacteria live in the intestines of humans and other mammals. When found in ground water, they indicate that disease-causing pathogens could also be present, and to be safe for drinking, the water needs to be disinfected. Because fecal coliform bacteria have been found at various concentrations at various times in many wells on Tutuila, all ground water supplied by the government water system is chlorinated. At the five wells where chlorinated samples were obtained, no coliform bacteria were detected. Seven of the 14 unchlorinated samples contained coliform bacteria and five of the seven contained fecal coliform bacteria, a subset of the total coliform bacteria found in the initial screening.

Three of the six unchlorinated water samples collected from the high-permeability unit contained fecal coliform bacteria. Two of the eight unchlorinated samples collected from the low-permeability unit contained fecal coliform bacteria. Fecal coliform bacteria were found in water from wells in both densely and sparsely populated areas, but the highest concentration was from the densely populated Utulei area (site 8), where the water table is 2 ft below the land surface. The next highest concentrations were in the Malaeimi and Tafunafou areas (sites 6 and 7), where the water table is about 100 ft below the land surface.

Fecal coliform bacteria thrive in the soil of warm and humid regions but generally are not found at depths greater than about 1 ft (Hardina and Fujioka, 1991). Fecal coliform bacteria in the ground water of Tutuila indicate that the recharge water carrying these bacteria may not have passed through sufficient soil material to remove them. This could happen naturally where fractures or permeable rock transmit water quickly to the water table, or may be human-induced by inadequate well construction or where cesspools or leaky sewer lines are located below the soil.

MAJOR IONS AND SILICA

The abundance of major ions and silica in ground water on Tutuila results primarily from seawater mixing with fresh ground water and from geochemical

Table 2. Summary of water-quality properties and chemical constituents in 19 pumped water samples collected from 17 drinking-water wells, Tutuila, American Samoa, May and July 1989

[MCL, maximum contaminant level (U.S. Environmental Protection Agency, 1986, 1989a); °C, degrees Celsius; µS/cm, microsiemens per centimeter at 25°C; NTU, nephelometric turbidity unit; col/100ml; number of colonies per 100 milliliters of water sample; -- value cannot be calculated; < value shown is greater than actual value; mg/L, milligrams per liter; µg/L, micrograms per liter; n, none; NA, not applicable; *, regulated by U.S. Environmental Protection Agency (1986); **, value is estimated by using a log-probability regression to predict the values of data below the reporting limit]

Property or constituent	Reporting limit	Maximum	Site no. (fig. 2) at which maximum measured	Minimum	Mean	MCL
Physical properties						
Temperature (°C)	0.5	29	7	25.5	26.74	n
pH	0.1	7.7	11	6.3	7.20	n
Hardness (mg/L as CaCO ₃)	1	1,500	14	41	219.0	n
Dissolved solids (mg/L)	1	2,370	14	116	437.6	n
Specific conductance (µS/cm)	1	4,650	14	150	760	n
Turbidity (NTU)	0.1	3.6	17	0.1	0.53	1-5
Bacteria						
*Total coliform (colonies/100 ml)	1	>1,600	5	<1	-	n
*Fecal coliform (colonies/100 ml)	1	>240	8	<1	**25	<1
Major nutrients (total recoverable)						
Ammonia and organic nitrogen (mg/L as N)	0.2	0.5	6	<0.2	-	n
Phosphorus (mg/L)	0.01	0.16	16	0.02	0.076	n
Major ions and other inorganic constituents (dissolved)						
Chloride (mg/L)	0.1	1,400	14	8.8	169.16	n
Sodium (mg/L)	0.1	210	14	12	54.58	n
Calcium (mg/L)	0.1	450	14	6.9	51.45	n
Magnesium (mg/L)	0.1	100	14	5.5	22.43	n
Potassium (mg/L)	0.1	18	4	1.6	6.25	n
Alkalinity (mg/L as CaCO ₃)	1	156	2	43	92.2	n
Sulfate mg/L	a ₅	120	14	<5	**19.56	n
Nitrate and nitrite (mg/L as N)	0.1	22	2	0.11	0.56	10
Fluoride (mg/L)	0.1	0.8	4	0.1	0.20	4.0
Silica (mg/L)	0.1	52	10	27	39.74	n
Iron (µg/L)	3	40	14	<3	**13.5	n
Manganese (µg/L)	1	12	16	<1	**2.4	n
Metals and other inorganic constituents (total recoverable)						
*Arsenic (µg/L)	1	<1	NA	<1	<1	n
*Barium (µg/L)	100	100	several	<100	100**	50
*Cadmium (µg/L)	1	<1	NA	<1	<1	1,000
*Chromium (µg/L)	1	6	14	<1	1.8**	10
*Lead (µg/L)	1	2	several	<1	1.6**	50
*Mercury (µg/L)	0.1	0.2	7 and 8	<0.1	0.063**	2
*Selenium (µg/L)	1	<1	NA	<1	<1	10
*Silver (µg/L)	1	4	16	<1	1.1**	50
Zinc (µg/L)	10	160	17	<10	18**	n
Iron (µg/L)	10	160	17	<10	36**	n
Manganese (µg/L)	10	20	16	<10	-	n
Copper (µg/L)	1	73	7	<6	6.4**	n
Trihalomethanes (THMs) from volatile organic analysis (total recoverable)						
*Bromoform	0.2	12	17	<0.2	1.94**	Sum of all THMs less than 100 µg/L
*Chloroform (µg/L)	0.2	4	8	<0.2	0.39**	
*Dibromochloromethane (µg/L)	0.2	22	8	<0.2	1.77**	
*Dichlorobromomethane (µg/L)	0.2	11	8	<0.2	-	
*Dechlorodifluoromethane (µg/L)	0.2	<0.2	NA	<0.2	<0.2	n

^a Reporting limit for sulfate is generally 0.1 mg/L. Conditions in the laboratory at the time of these analyses required that the limit be increased to 5 mg/L

Table 3. Chemicals for which concentrations were below the reporting limit in 19 pumped water samples collected from 17 drinking-water wells on , Tutuila, American Samoa, May and July, 1989

[MCL, maximum contaminant level (U.S. Environmental Protection Agency, 1986, 1989b); µg/L, micrograms per liter; --, none; PCB polychlorinated biphenyl; PCN, polychlorinated naphthalene; *, regulated by U.S. Environmental Protection Agency]

Chemical	Reporting limit	MCL	Chemical	Reporting limit	MCL
Organophosphorous insecticide (total recoverable)					
Diazinon (µg/L)	0.01	—	Benzene* (µg/L)	0.2	5
Chlorpyrifos (µg/L)	0.01	—	Toluene (µg/L)	0.2	—
Malathion (µg/L)	0.01	—	Xylenes mixed (µg/L)	0.2	—
Parathion (µg/L)	0.01	—	Styrene (µg/L)	0.2	—
Trithion (µg/L)	0.01	—	Carbon tetrachloride* (µg/L)	0.2	5
Methylparathion (µg/L)	0.01	—	Chlorobenzene (µg/L)	0.2	—
Methyltrithion (µg/L)	0.01	—	Chloroethane (µg/L)	0.2	—
Ethion (µg/L)	0.01	—	Vinyl chloride* (µg/L)	0.2	2
			Ethylbenzene (µg/L)	0.2	—
Organochlorine insecticide (total recoverable)					
Endrin* (µg/L)	0.01	0.2	Methylbromide (µg/L)	0.2	—
Lindane* (µg/L)	0.01	4	Methylene chloride (µg/L)	0.2	—
Methoxychlor* (µg/L)	0.01	100	Methylchloride (µg/L)	0.2	—
Toxaphene* (µg/L)	1	5	Tetrachloroethylene PCE (µg/L)	0.2	—
Aldrin (µg/L)	0.01	—	Trichloroethylene TCE* (µg/L)	0.2	5
Chlordane (µg/L)	0.10	—	1-2-Dibromoethane EDB (µg/L)	0.2	—
DDD (µg/L)	0.01	—	1-2-Dichloropropane (µg/L)	0.2	—
DDT (µg/L)	0.01	—	1-3-Dichloropropane (µg/L)	0.2	—
DDE (µg/L)	0.01	—	Cis-1-3-Dichloropropene (µg/L)	0.2	—
Dieldrin (µg/L)	0.01	—	Trans-1-3-Dichloropropene (µg/L)	0.2	—
Endosulfan (µg/L)	0.01	—	2-Chloroethyl vinyl ether (µg/L)	0.2	—
Heptachlor (µg/L)	0.01	—	1-2-Dichlorobenzene (µg/L)	0.2	—
Heptachlor epoxide (µg/L)	0.01	—	1-3-Dichlorobenzene (µg/L)	0.2	—
Mirex (µg/L)	0.01	—	1-4-Dichlorobenzene* (µg/L)	0.2	75
Perthane (µg/L)	0.1	—	1-1-Dichloroethane (µg/L)	0.2	—
Gross PCB (µg/L)	0.1	—	1-2-Dichloroethane* (µg/L)	0.2	5
Gross PCN (µg/L)	0.1	—	1-1-Dichloroethylene* (µg/L)	0.2	7
			1-2-trans-Dichloroethylene (µg/L)	0.2	—
Chlorophenoxy acid herbicide (total recoverable)					
2-4-D* (µg/L)	0.01	100	1-1-2-2-Tetrachloroethane (µg/L)	0.2	—
2-4-5-TP (Silvex)* (µg/L)	0.01	10	1-1-1-Trichloroethane* (µg/L)	0.2	200
2-4-DP (µg/L)	0.01	—	1-1-2-Trichloroethane (µg/L)	0.2	—
2-4-5-T (contains Dioxin) (µg/L)	0.01	—	Trichlorofluoromethane (µg/L)	0.2	—
			Dichlorodifluoromethane (µg/L)	0.2	—

processes. Leachate from agricultural areas or waste-disposal sites can increase the abundance of major ions in ground water, but such effects cannot be identified in these samples. The relative abundance of the major ions is shown in the water-quality diagrams in figure 5 in which concentrations of major ions are represented by distance from a vertical center line. Concentrations are expressed in units of milliequivalents per liter to allow a direct comparison of negative and positive ions (reactive units), without regard to their atomic weights. To obtain concentrations in the commonly used unit of milligrams per liter, multiply the value in milliequivalents per liter by the following factors for each chemical species: sodium, 23.0; magnesium, 12.2; calcium, 20.0; chloride, 35.4; sulfate, 48.0; and bicarbonate, 61.0 (Hem, 1985). The sizes of the water-quality diagrams in figure 5 have been made approximately equal by using 4 different horizontal scales of equal length but which range in value from 2.5 to 50 milliequivalents per liter. Therefore, the shapes of the diagrams can be conveniently compared, although dissolved-solids concentrations range from about 100 to 2,400 mg/L.

At relatively low (less than about 300 mg/L) concentrations of dissolved solids, bicarbonate generally is the dominant anion (negative ion), and sodium, calcium, and magnesium are the dominant cations (positive ions) in the ground water (fig. 5). Bicarbonate in the ground water results from carbon-dioxide enrichment of the recharge water from the abundant carbon dioxide in the forest litter and upper soil zone, and subsequent interaction of the recharge water with soil and rock minerals. Sodium, calcium, and magnesium in the ground water result from the dissolution of minerals and from small amounts in rainfall. The chemical composition of dissolved constituents in rainfall is similar to that in sea salt, in which sodium and chloride are the primary ions (Bogen and others, 1984). Sodium and chloride generally become the dominant ions in ground water with increasing major ion concentrations, indicating increased mixing with seawater. Exceptions are at brackish-water wells in the low-permeability unit (sites 12, 14, and 15), where sodium is depleted relative to chloride. Sodium depletion may be the result of geochemical processes in which sodium initially in the brackish ground water is exchanged for calcium and magnesium in the rock minerals, while the chloride ions remain in solution (Visher and Mink, 1964).

Of the constituents resulting from the dissolution of rock minerals, silica is found in the highest concentrations in the ground water of Tutuila. Silica concentrations averaged 38 mg/L in water from the lava flows of the high-permeability unit of the Tafuna-Leone

plain, where the silica content of the basalt lava flows is relatively low (Natland, 1980) and ground-water residence times are short. Silica concentrations averaged 44 mg/L in water from the low-permeability volcanic rock unit of Pleistocene age, where the silica content is higher and ground-water residence times are longer. Other rock mineral constituents such as sodium, magnesium, potassium, iron, and aluminum, as well as other trace metals, are retained to a relatively greater degree in the residual clays formed by the leaching of silica from the original basalt minerals.

ORGANIC COMPOUNDS

The USEPA maximum contaminant level (MCL) of the trihalomethane (THM) class of volatile organic compounds is 100 µg/L because of the potential carcinogenic effect of these compounds (table 2). THM can be formed by the reaction of chlorine with naturally occurring organic matter. Levels below the MCL were found in all five samples where well water was chlorinated before sampling. No THM was found where water was chlorinated after sampling. Chlorine disinfectant was injected directly into wells at sites 3, 8, and 17. THM concentrations in samples from these sites were 13 µg/L, 47 µg/L, and 14 µg/L, respectively. Chlorine was put into the distribution line before the sample-collection points at sites 1 and 15. THM concentrations in samples from these wells were 10 µg/L, and 4 µg/L, respectively. The water samples were analyzed for other volatile organic compounds such as those commonly found in fuel, solvents, and some pesticides, but none were detected (table 3).

Table 4. Commonly used pesticides on Tutuila, American Samoa

Pesticide name	Family
<u>Herbicide</u>	
Paraquat	bipyridyl
<u>Fungicide</u>	
Benlate	carbamate
Mancozeb	carbamate
Calixin	maneb
<u>Insecticide</u>	
Diazinon	organophosphorous
Dursban	chlorpyrifos
Malathion	organophosphorous
Pyra-Kill	pyrethrin
Baygon	carbamate
Vikane	sulfuryl fluoride

Work by Rao and others (1985) indicates that under normal conditions there is relatively little risk that the commonly used chemicals on Tutuila (table 4) will l

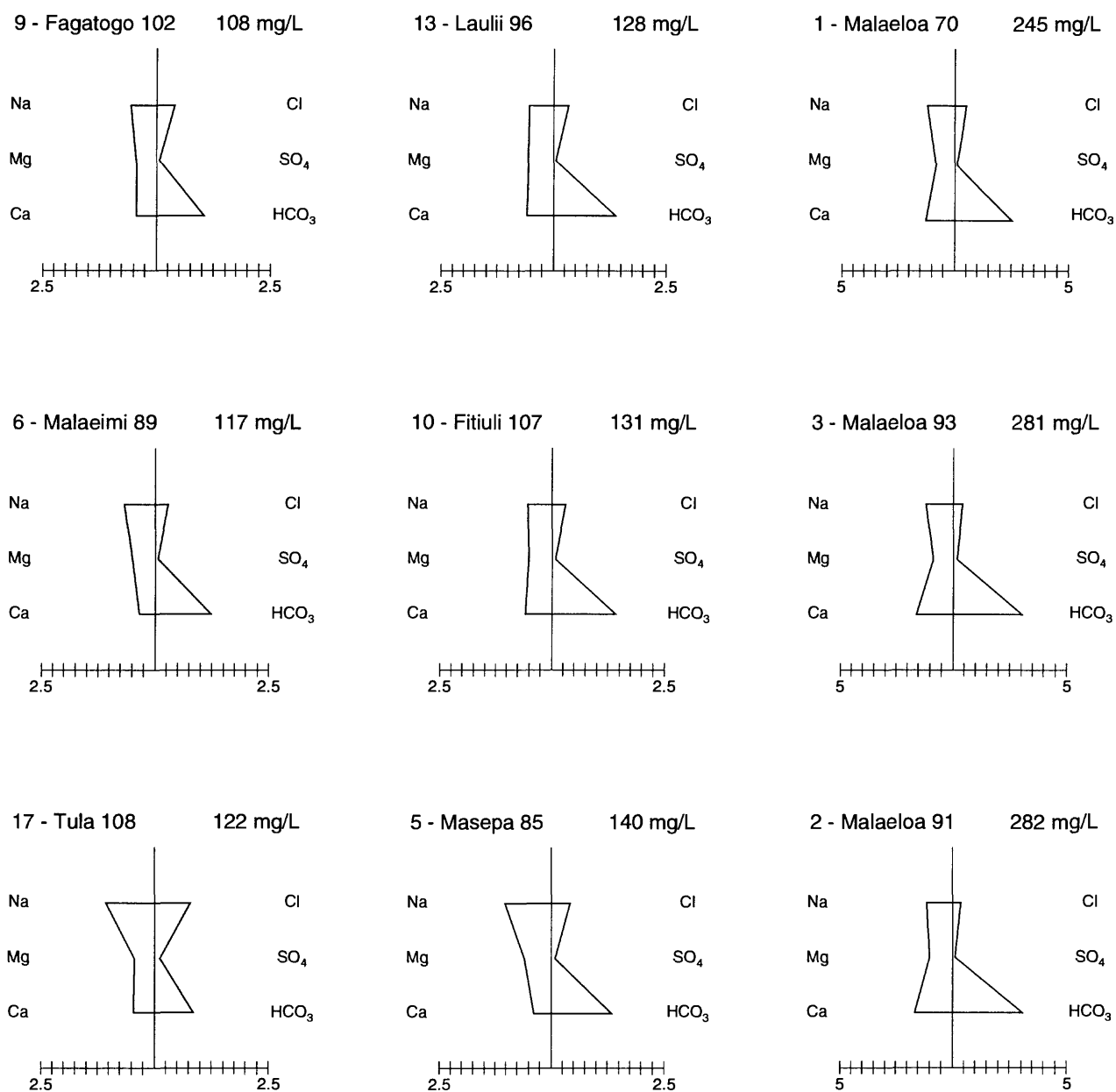
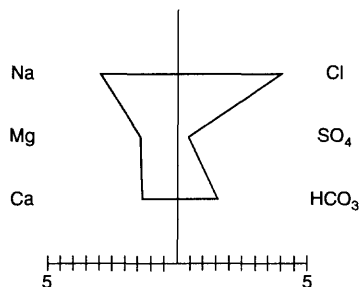
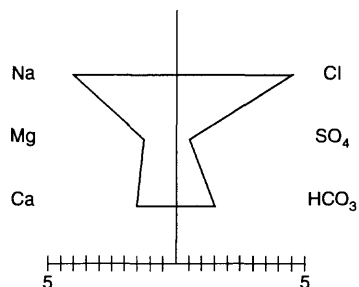


Figure 5. Dissolved-solids concentrations (in milligrams per liter) and concentrations of major ions (in milliequivalents per liter) in ground water, Tutuila, American Samoa.

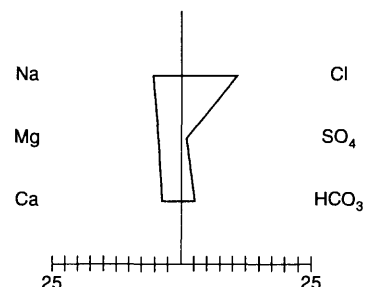
16 - Tula 104 367 mg/L



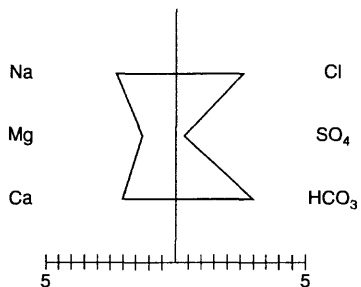
11 - Pago Plaza 2 411 mg/L



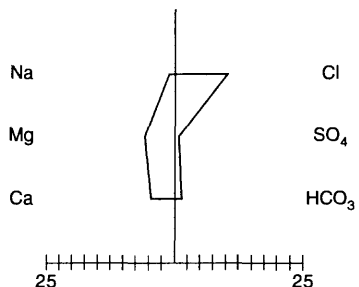
15 - Sailele 130 852 mg/L



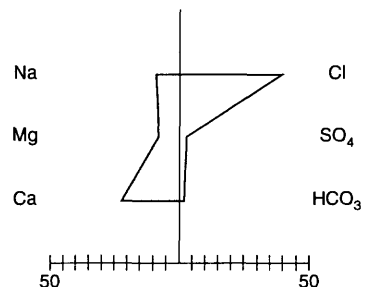
8 - Utulei 3 404 mg/L



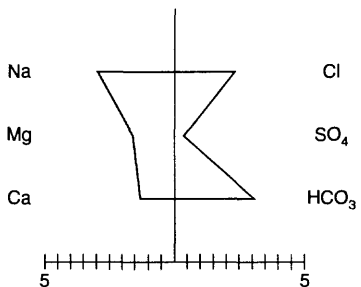
12 - Aua 99 675 mg/L



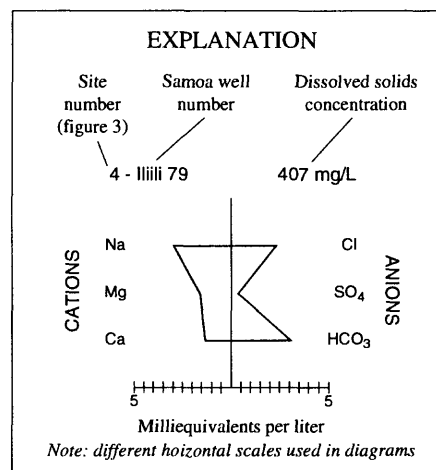
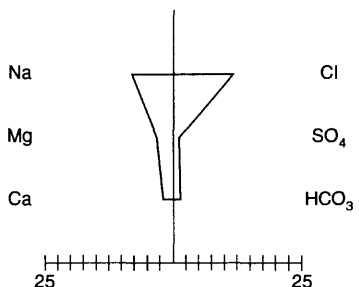
14 - Alofau 32 2,372 mg/L



4 - Ilili 79 407 mg/L



7 - Tafuna 33 802 mg/L



each into the ground water. By calculating retardation and attenuation factors, Rao and others (1985) ranked 41 pesticides with regard to their potential to move through the unsaturated zone and enter underlying ground water. A rank of 1 indicates the highest potential for leaching. Of the pesticides commonly used on Tutuila, Diazinon, Dursban, and Malathion ranked 15, 36, and 41, respectively. These three chemicals, as well as a broad, but by no means complete, suite of other insecticides and herbicides were analyzed for this study and none were detected (table 3). Half-lives, volatility, and adsorption coefficients (Wauchape and others, 1992) of the other pesticides commonly used on Tutuila listed in table 4 indicate that, in general, these pesticides are less likely than Malathion to leach to the ground water. Consideration of general chemical characteristics is appropriate for estimating the relative likelihood of nonpoint-source contamination from various chemicals applied under similar circumstances. The likelihood of point-source contamination resulting from product misuse, spill, or locally unfavorable climatic or soil and rock conditions cannot be addressed in this way.

SUMMARY AND CONCLUSIONS

In May and July 1989, nineteen ground-water samples were collected from 17 of the 35 water-supply wells on the 53 square mile volcanic island of Tutuila, American Samoa. Sampled wells were in residential areas, areas of commercial agriculture, and areas relatively undisturbed by human activity. The primary purpose was to evaluate drinking water at the wellhead with regard to the U.S. Environmental Protection Agency's primary drinking-water regulations. Samples were analyzed for temperature, pH, hardness, specific conductance, and turbidity, as well as total and fecal coliform bacteria, major ions, major nutrients, 12 common metals, and 66 organic compounds that included insecticides, herbicides, and volatile organic compounds. The results of this study indicate that the common ground-water contaminants on Tutuila are bacteria and seawater.

Wells on Tutuila tap a freshwater lens that floats on the saltwater that has intruded the basalt aquifers formed by the two geohydrologic units of Tutuila: (1) the low-permeability unit made up primarily of deeply weathered and eroded Pleistocene volcanic rocks, and (2) the high-permeability unit made up primarily of the Holocene lava flow that formed the 11 square mile Tafuna-Leone plain on the south-west side of the island. The altitude of the freshwater-saltwater interface varies throughout the island, from less than several tens of feet

below sea level to more than several hundred feet below sea level.

Concentrations of dissolved solids in the samples ranged from about 100 to about 2,400 milligrams per liter. Four samples had concentrations of dissolved solids and chloride that exceeded the USEPA secondary drinking-water regulations of 500 and 250 milligrams per liter, respectively. For samples with less than 300 milligrams per liter of dissolved solids, sodium, calcium, and magnesium were the dominant cations, bicarbonate was the dominant anion, and the dissolved constituents were primarily a result of dissolution of minerals and carbon-dioxide enrichment of recharge water. For samples with greater than 300 milligrams per liter of dissolved solids, the primary dissolved constituents were sodium and chloride, indicating increased mixing with seawater. For the three wells in the low-permeability unit with high dissolved solids, geochemical reactions seem to have additionally depleted the sodium and enriched the calcium and magnesium concentrations.

Potential for ground water contamination by land-use activities may be greater on the high-permeability unit than on the low-permeability unit. Three of the six unchlorinated water samples collected from the high-permeability unit contained fecal coliform bacteria, whereas only two of the eight unchlorinated samples collected from the low-permeability unit contained fecal coliform bacteria. Fecal coliform bacteria were found in water from wells in both densely and sparsely populated areas but the highest concentration was found in a shallow well near sea level in a densely populated area on the low-permeability unit.

Because Tutuila well water commonly contains bacteria, all water distributed in the government water system is chlorinated. Of the five samples collected after chlorination, all contained trace levels of trihalomethanes at concentrations below U.S. Environmental Protection Agency maximum contaminant levels. Trihalomethanes were the only organic constituents detected.

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